



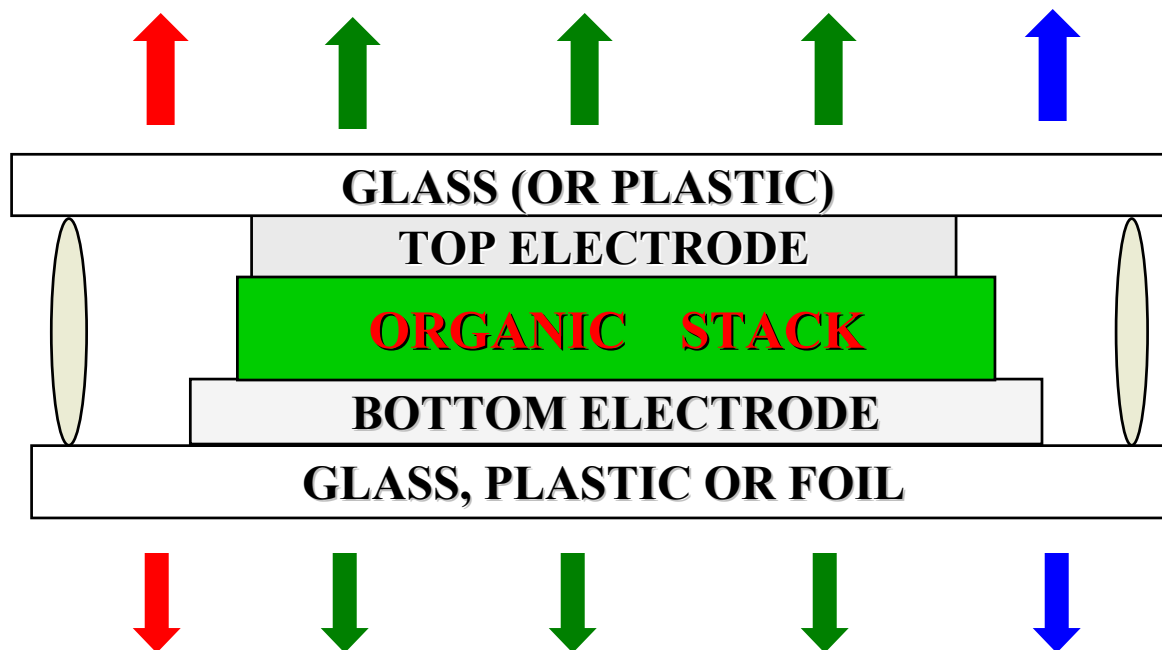
OLEDs: The History and Future Trends

Mike Hack

Universal Display Corporation

**375 Phillips Boulevard, Ewing, NJ 08618
www.universaldisplay.com**

Why OLED?



And...

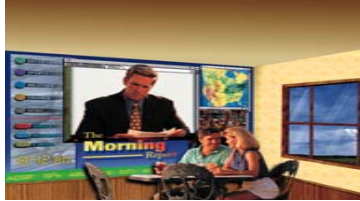
Transparency

Flexibility

- Bright
- Power efficient
- Thin
- Wide viewing angle
- Video Rate
- Low manufacturing cost



Flat Panel Displays



Wall-mounted TVs

PDAs



Automotive clusters



Passenger entertainment



Cell phones



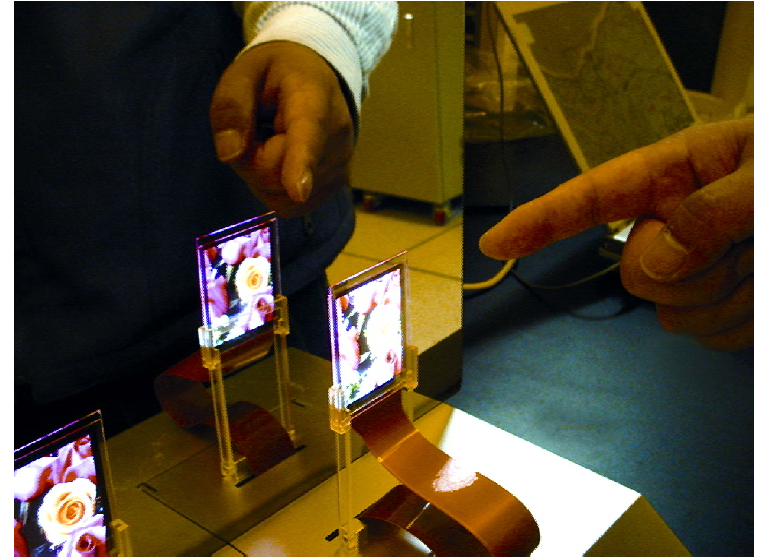
Laptops

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- Demonstrated 2.2" Transparent AMOLED at SID 2003
- Demonstrated 15.5" AMOLED Monitor Display at SID 2003



*Images courtesy of H. K. Chung,
Samsung SDI*

OLED Display Roadmap



Small Area
Sector
OLED
Products



Flexible
OLEDs



Small Area
Full-color
OLED
Products

Large Area
Product
Prototypes

Transparent
OLEDs



Full-color
Product
Prototypes

2003



Small Area
Multi-color
OLED
Products



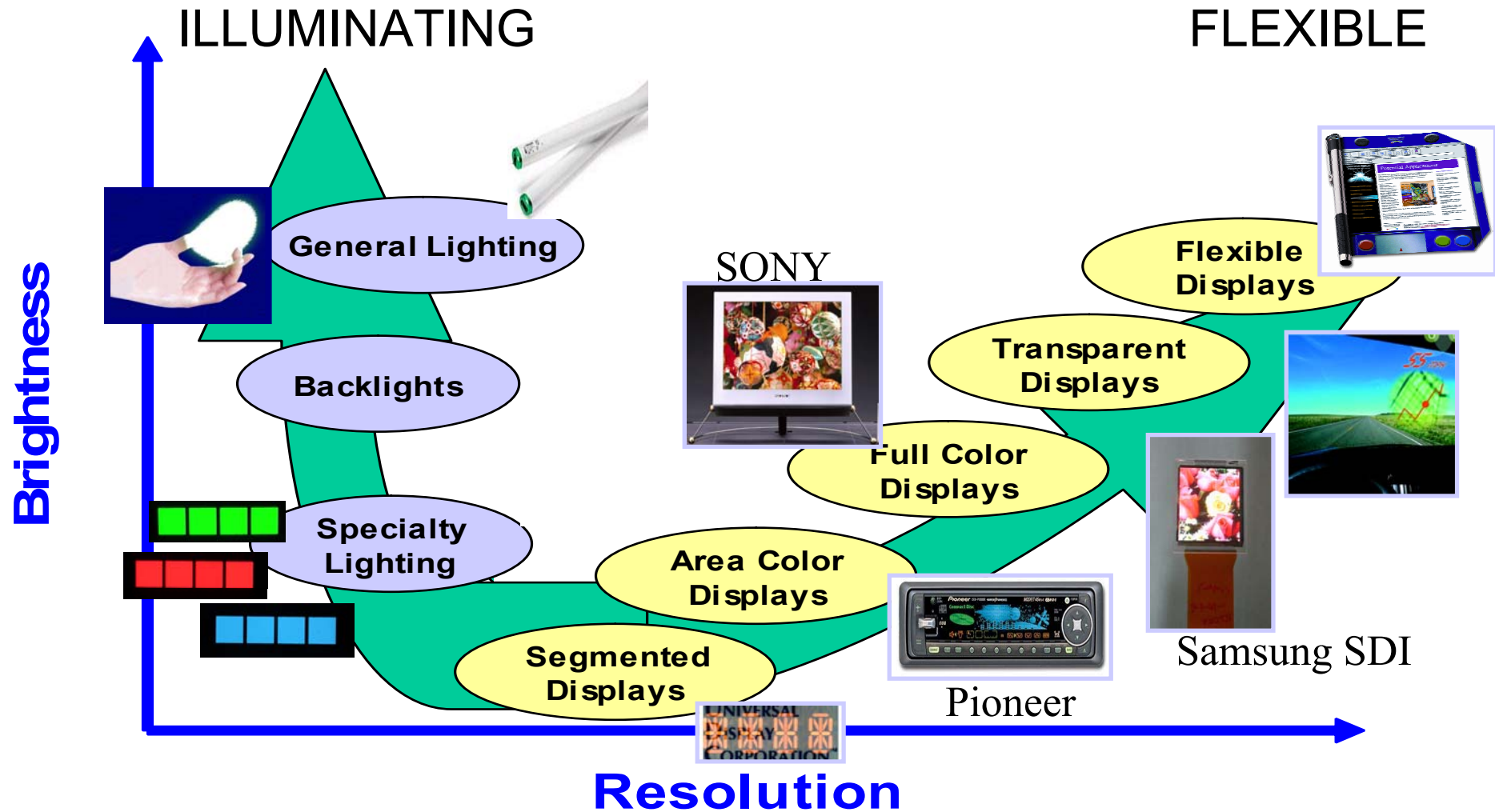
Phosphorescence is key to rapid OLED commercialization

1997

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OLED Product Roadmap

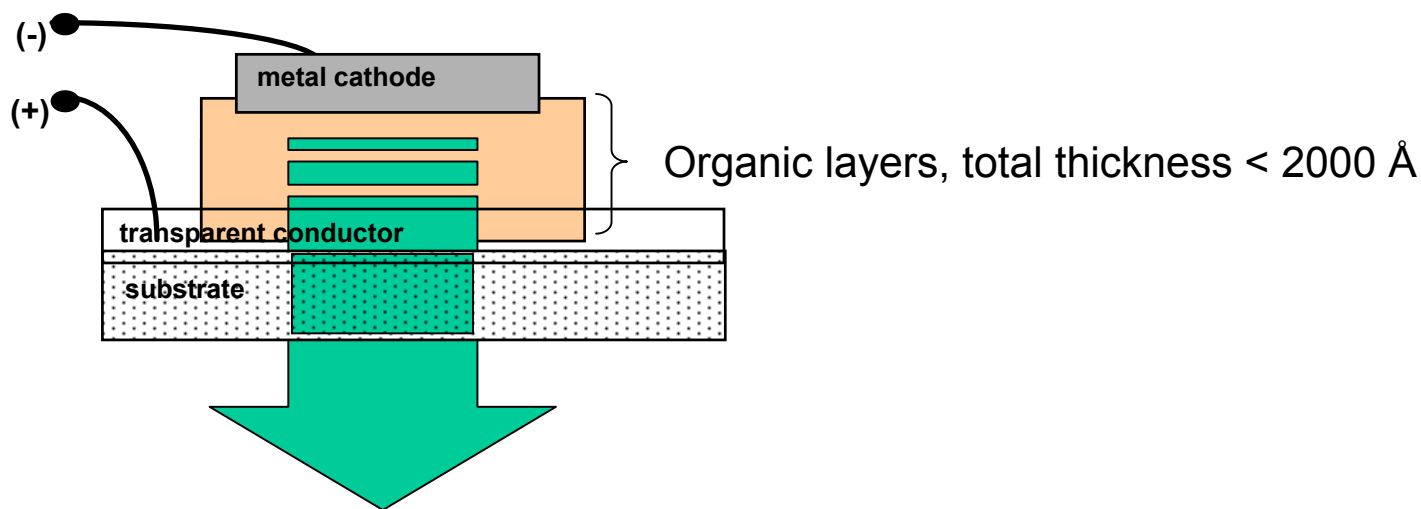


Key milestones in OLED history

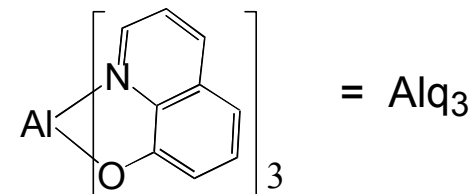
- Organic materials emit light under current injection (~1970)
- Heterojunction small molecule device (1986)
- Fluorescent doping of emissive layer to improve efficiency (1987)
- First polymer OLED device (1990)
- Phosphorescent OLEDs (PHOLED™) (1997)
- First passive commercial product (1997)
- First active matrix OLED product (2003)



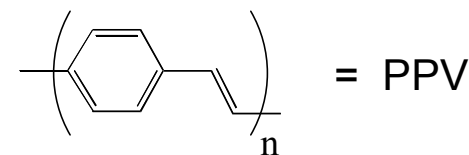
First Efficient OLEDs



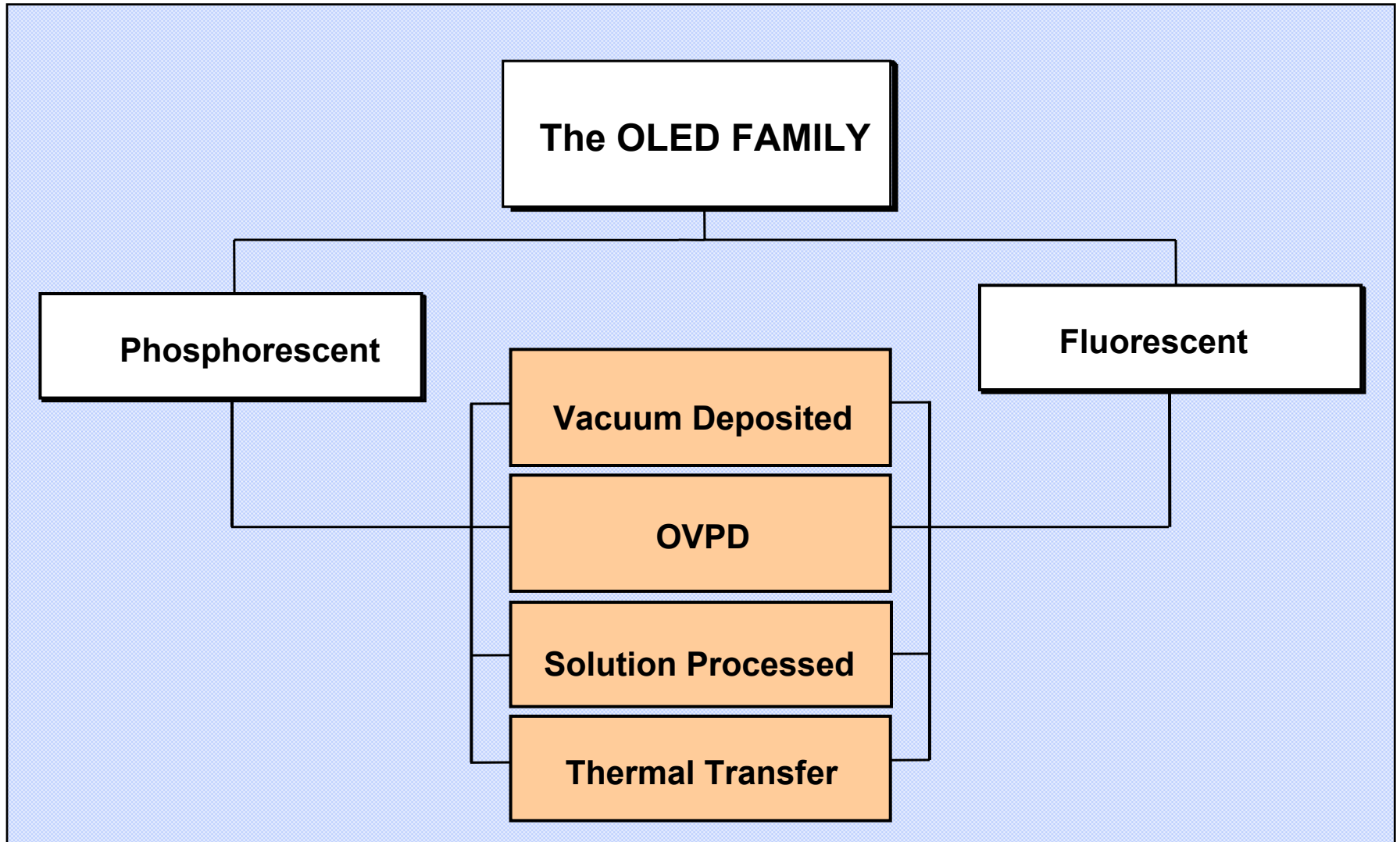
- First efficient LED with a molecular organic emissive layer reported by Tang and VanSlyke, *Apl. Phys. Let.*, **1987**, emitter = **Alq₃**.



- First report of an LED fabricated with a polymeric emissive layer reported by Friend, *et. al.*, *Nature*, **1990**, emitter = **PPV**.



The OLED Family



OLED Power Efficiency

$$\eta_P \propto \eta \eta_{OUT} \eta_{ELEC}$$

η_P = Power efficiency

η = Quantum efficiency

Fluorescence: Radiation restricted to singlet excitons, i.e., 1 of 4 spin states or ~25%.

Phosphorescence: Radiation is from triplets, i.e., 4 of 4 or ~100%.

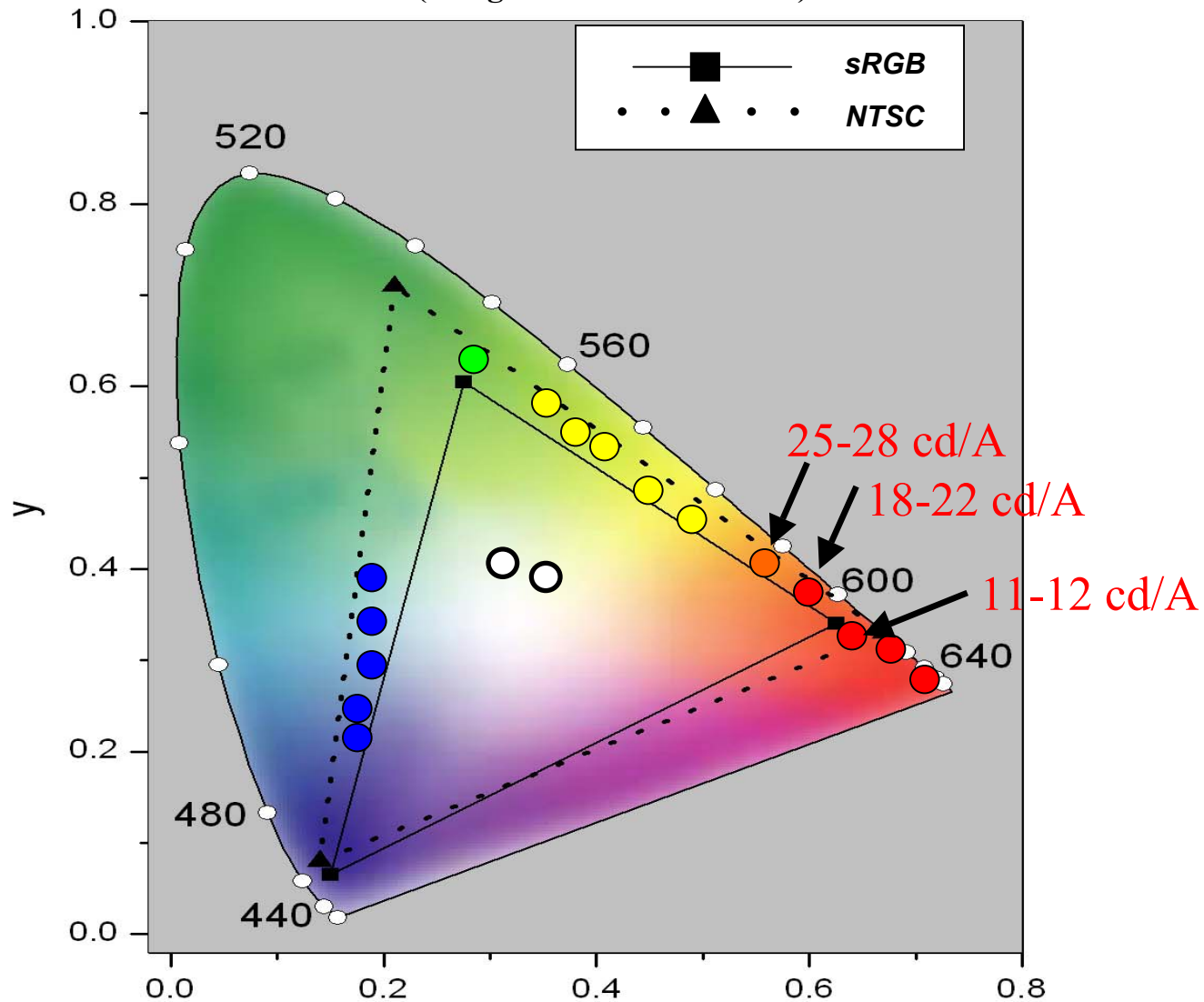
η_{OUT} = Light extraction efficiency, typically ~20%

η_{ELEC} = Electrical efficiency ($= V_\lambda / V$ where V_λ = photon energy, V = operating voltage)

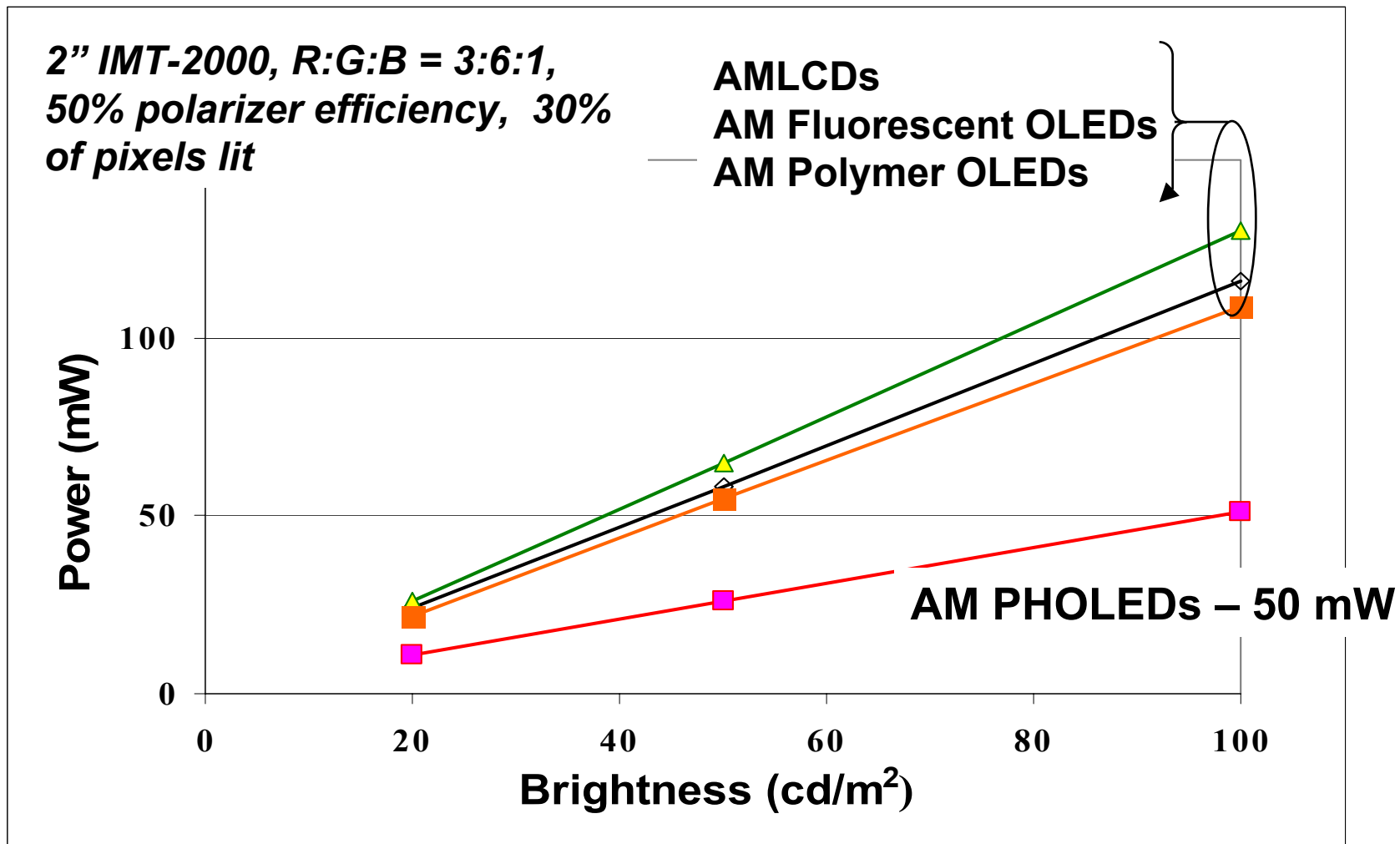


PHOLEDs Color Coordinates

(using the 1931 CIE Chart)



Cell Phone Power Consumption Comparison

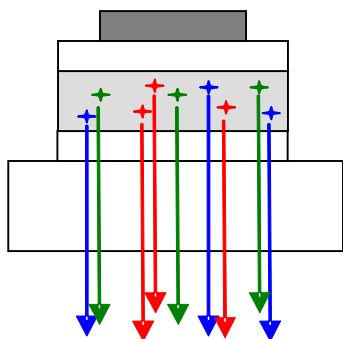


Why White OLEDs?

- **Displays** – alternative approach using white OLEDs and color filters
- **Backlights** – alternative to conventional liquid crystal display (LCD) fluorescent backlights
- **General Lighting** – alternative to current lighting options, i.e. incandescent bulbs, fluorescent bulbs
- *Requirements vary for each application*

Methods for Obtaining White PHOLEDs

- Three color OLED in one mixed layer



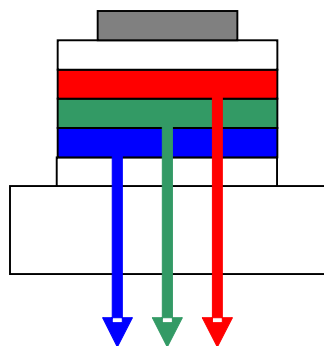
Pros:

- Simple structure

Cons:

- Low efficiency
- Highly precise doping required (energy transfer between dopants)

- Three color OLED in separate layers



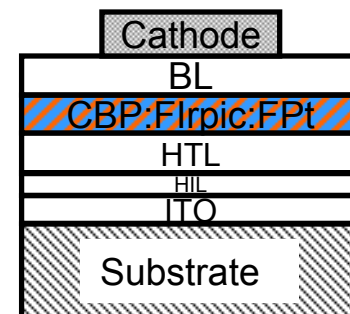
Pros:

- straightforward
- high efficiency

Cons:

- Many EMLs / complex structure
- chromaticity stability (time and drive current)

- Monomer Excimer emission



Pros:

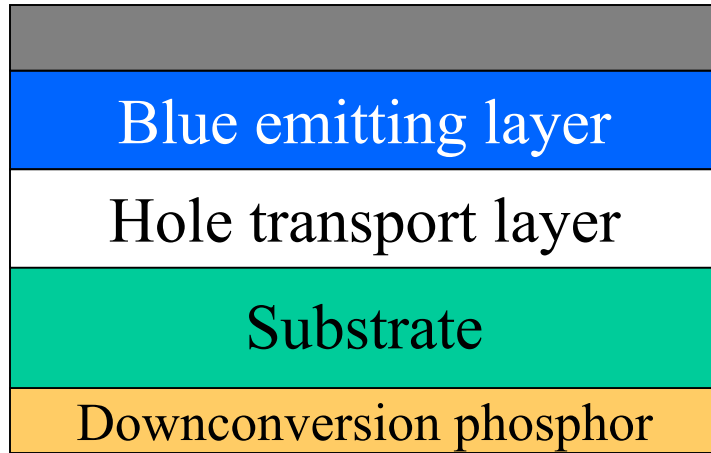
- very simple, single dopant

Cons:

- Lifetime (currently)



Routes to White OLED (II): Downconverted Blue



Cathode

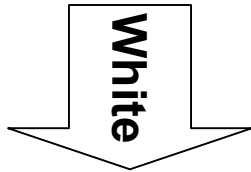
Blue emitting layer

Hole transport layer

Substrate

Downconversion phosphor

Transparent Anode



Duggal et al. Appl. Phys. Lett. **80**, 3470 (2002)
4 lm/W at 1000 cd/m², 1.3% WPE
Later results → 7 lm/W

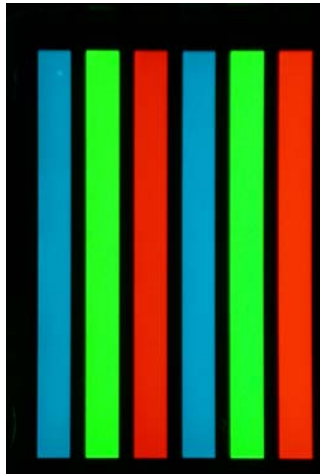
Pro: Simple structure
No color shifts

Con: Blue is the toughest OLED color to make efficient and stable
Efficiency loss due to Stokes shifts in phosphor

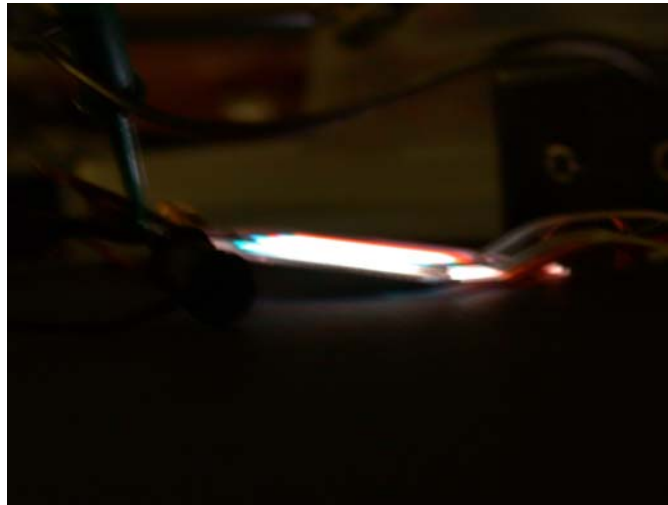


The Electrochemical Society *Interface* • Summer 2003 p.42

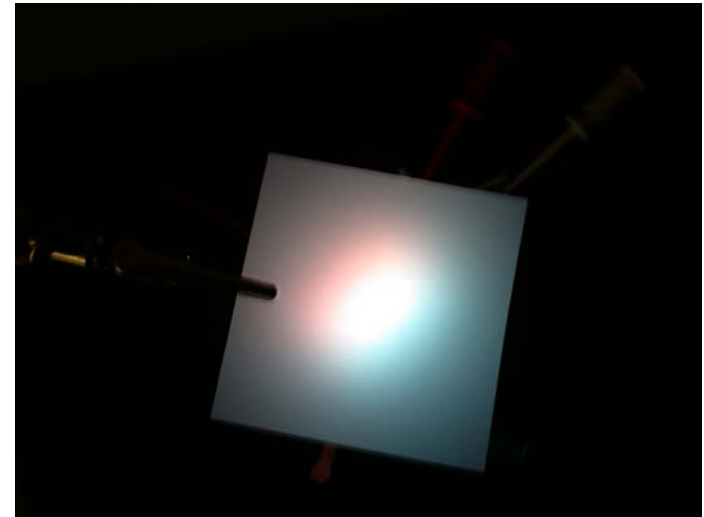
Alternative Approach to White Lighting Stripes



Close up – top view
no diffuser



Shallow angle view – no diffuser



Top view with a diffuser

How to Achieve White Lighting from OLED at $> 100 \text{ lm/W}$

- 1) Identify white light emitting system
- 2) Convert all electrical charge to photons
 $\approx 100\%$ Internal quantum efficiency -- *Phosphorescence*
- 3) Ensure that as many photons as possible are radiated (outcoupling efficiency)
 - Use texturing or low index refraction layers
- 4) Reduce drive voltage close to photon energy
 - Good injecting contacts
 - High mobility transport layers
 - Doped transport layers
 - Device engineering e.g. graded interfaces

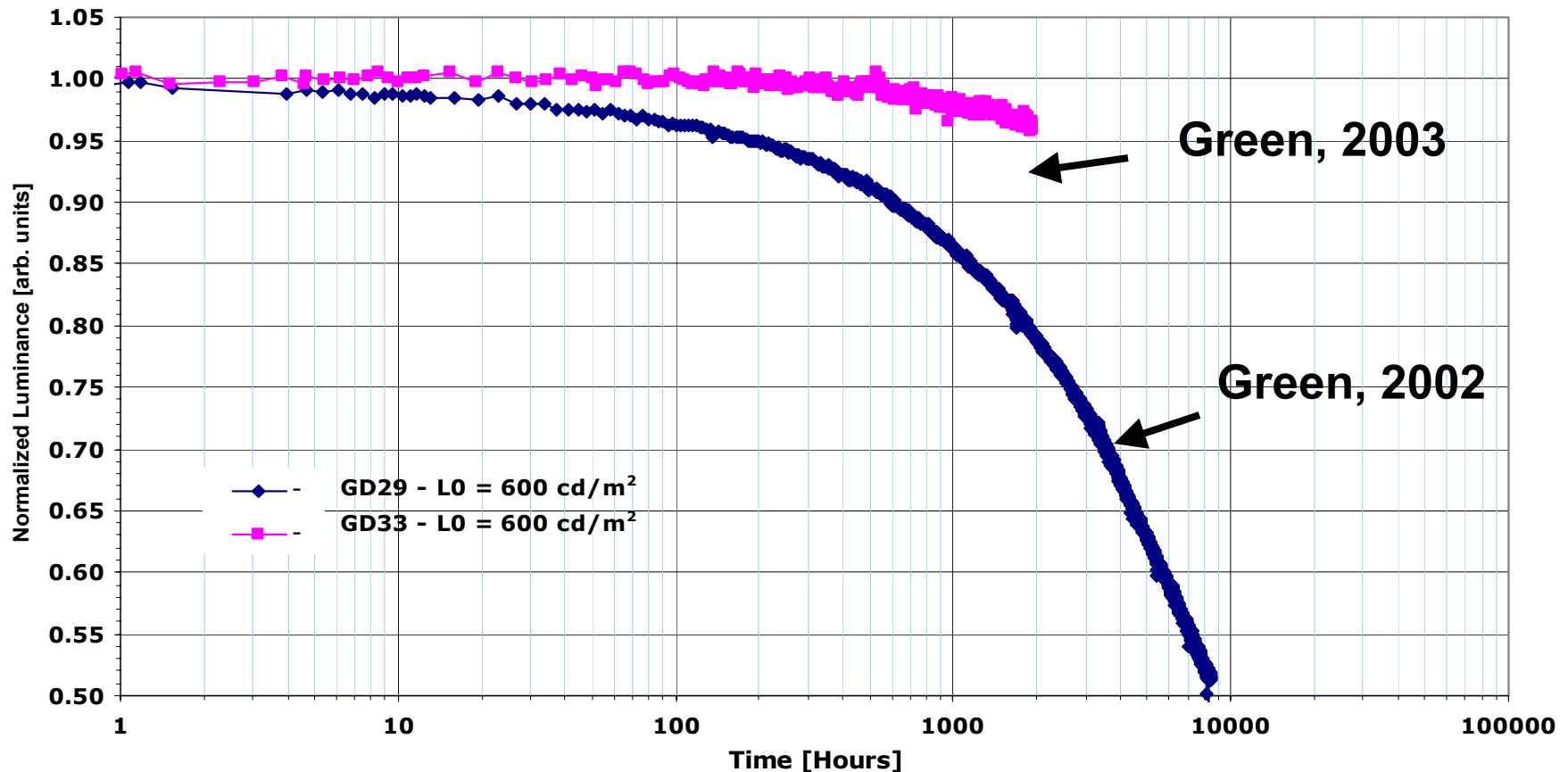


Achieving 100 lm/W OLEDs !

Parameter	Current Status	Practical Limit
Light extraction	~ 20%	40%, with outcoupling enhancement
Brightness (cd/m ²)	800	Trade-off with lifetime
Lifetime (hrs.)	10,000 (R, G)	TBD
R luminous eff (cd/A)	14	48
G luminous eff (cd/A)	28	140
B luminous eff (cd/A)	10	48
Device Voltage	6 - 8	3.2
Lifetime for 800 cd/m ²	5,000	20,000
Power efficiency (lm/W)	10 - 15	108

Rapid Improvement in PHOLED Device Lifetimes

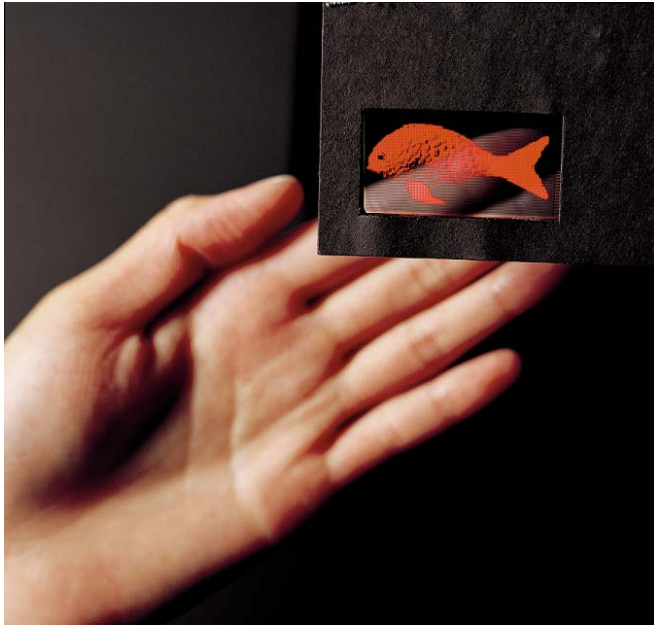
Performance at $L_0=600\text{nits}$ (room temperature)



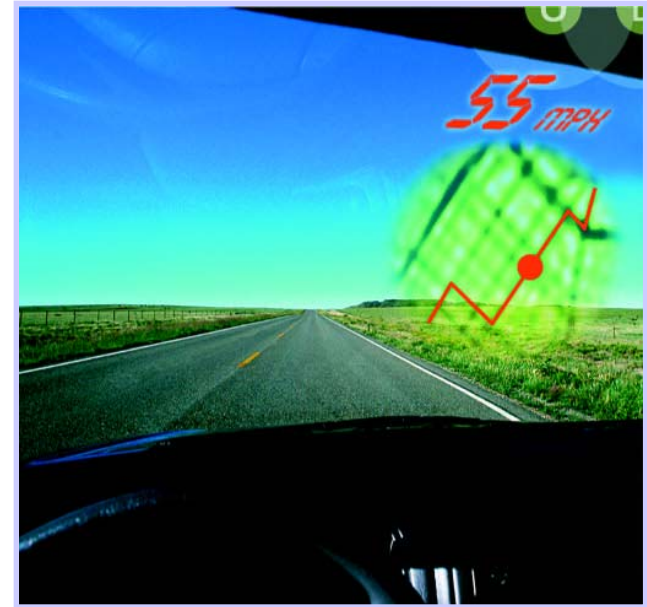
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Transparent OLEDs (TOLEDs™)

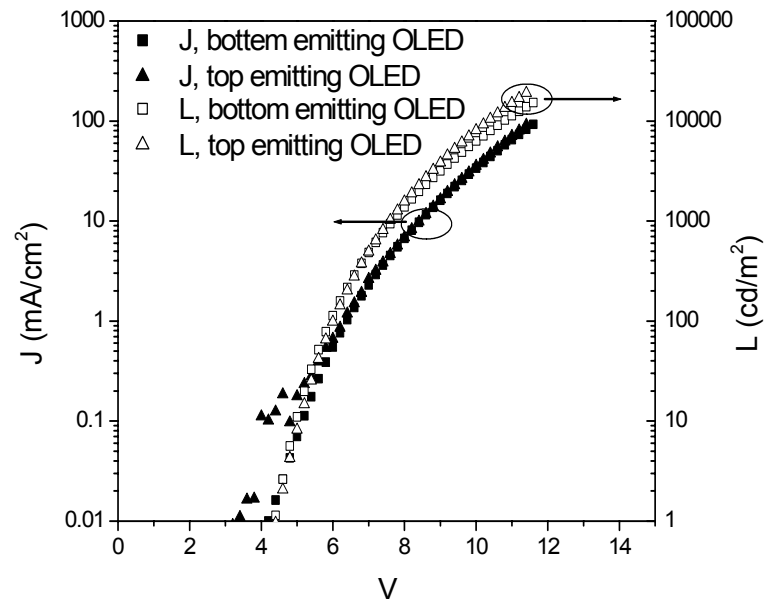
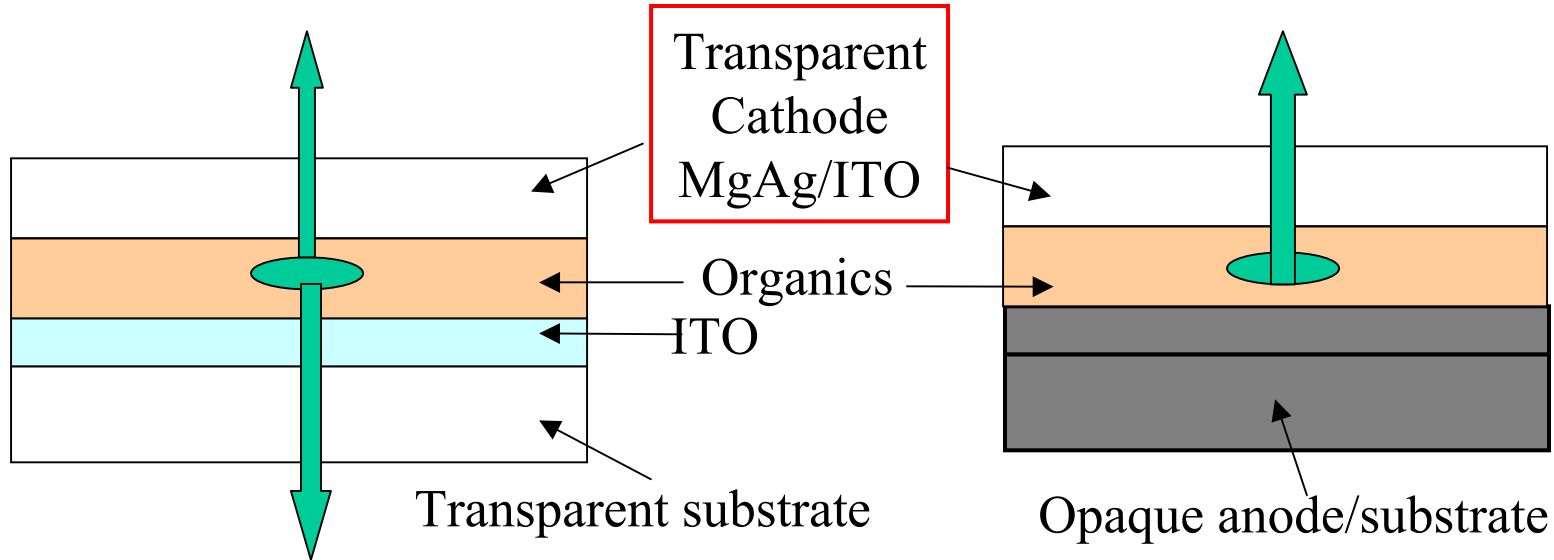


UDC Prototype



Application Concept

Transparent / Top Emission OLEDs (TOLEDs)



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55 mph



DVD

CD

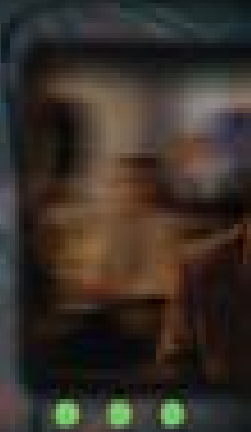
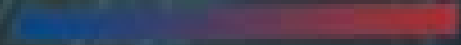


TRAFFIC MONITOR



ACIDIC

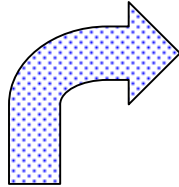
HEAT



What's Next – OLED Displays

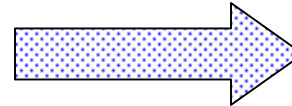
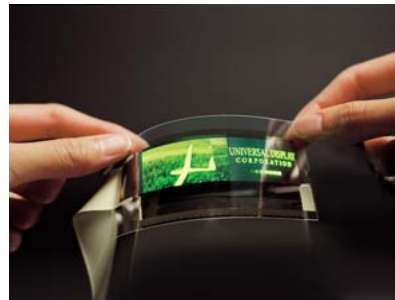
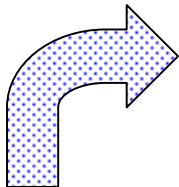
Continuous Manufacturing Process

*Thin
Light Weight
Conformable FPDs*



Courtesy P.E. Burrows, PNNL

In-Flex Use Products



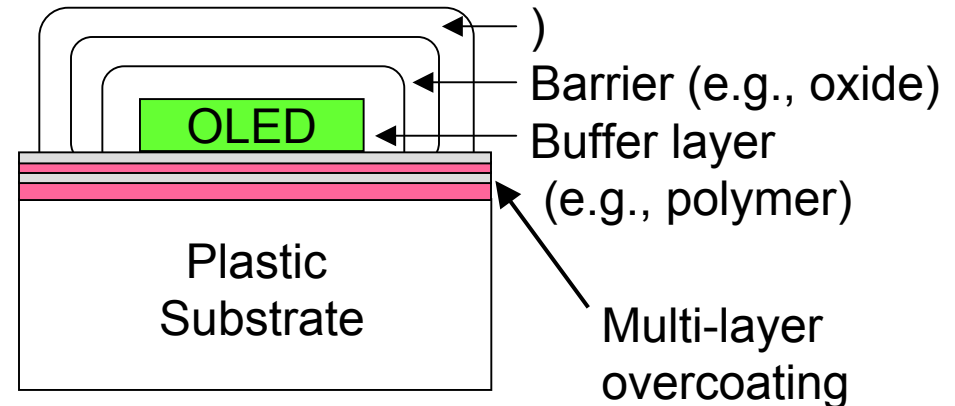
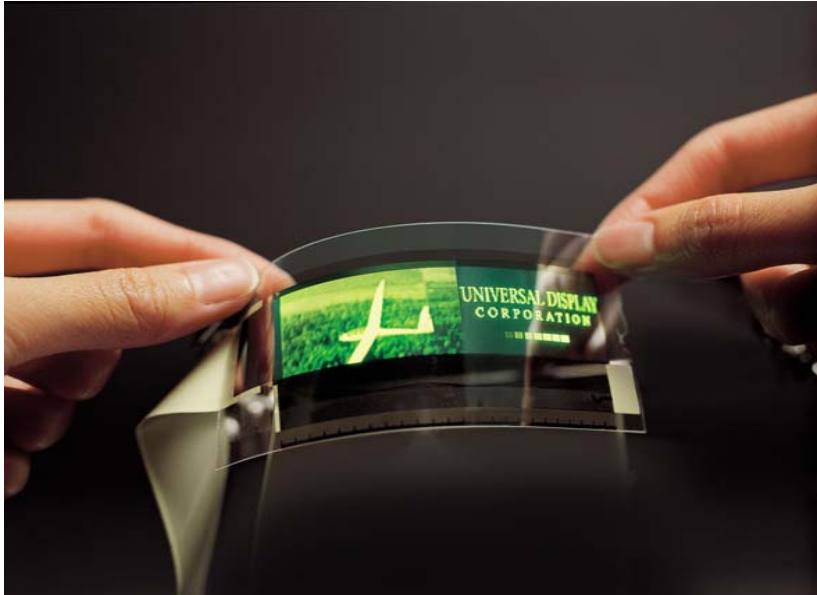
GLASS

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Encapsulation of OLEDs on Plastic

Joint UDC / Vitex development program
partially funded by DARPA/ARL



- Hermetic sealing system
- No glue lines or edge seals
- Compatible with batch and roll-to-roll processes

Changing the way you view the world.



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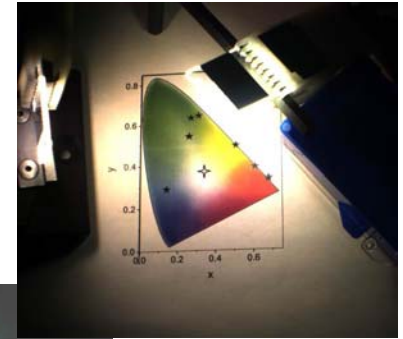
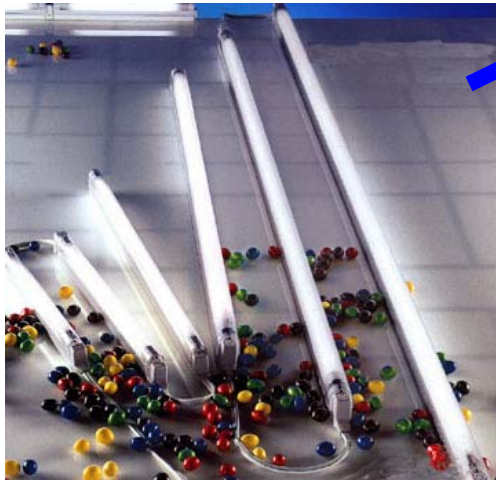






What's Next – OLED Lighting

PHOLEDs



TOLED Lighting Applications

Near-term

Appliances

Furniture

Architectural specialty lights

Backlights, e.g., for laptops

Avionic lighting

Interior windows

Ceilings



Longer-term

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Acknowledgements

A hand holding a pen is positioned above a logo for Universal Display Corporation. The logo consists of the company name in a serif font, with a stylized graphic below it featuring three overlapping triangles in green, red, and blue.

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- Steve Forrest, Mark Thompson and their research teams at Princeton University and the University of Southern California
- The entire UDC team
- The teams of R&D and Manufacturing Chemists at PPG Industries
- Funding in part by ARL, CECOM and DOE